

**INVESTIGATION OF AIR TRANSPORTATION
TECHNOLOGY
AT PRINCETON UNIVERSITY, 1988-1989**

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SUMMARY OF RESEARCH

The Air Transportation Technology Program at Princeton University, a program emphasizing graduate and undergraduate student research, proceeded along seven avenues during the past year:

- Microburst and Wind Shear Hazards to Aircraft
- Intelligent Flight Control Systems
- Real-time Cockpit Simulation
- Revitalization of General Aviation
- Alternatives for the Air Traffic Control System
- Stochastic Robustness of Flight Control Systems
- Neural Networks for Flight Control

It has become apparent that severe downdrafts and resulting high velocity outflows caused by microbursts present a significant hazard to aircraft on takeoff and final approach. Microbursts, which are often associated with thunderstorm activity, also can occur in the vicinity of dissipating convective clouds that produce no rainfall at ground level. Microburst encounter is a rare but extremely dangerous phenomenon that accounts for one or two air carrier accidents and numerous general aviation accidents each year (on the average). Conditions are such that an aircraft's performance envelope may be inadequate for safe penetration unless optimal control strategies are known and applied.

While a number of simulation studies have been directed at the problem, there are varied opinions in the flying community regarding the best piloting procedures, and optimal control strategies have only recently been defined. Graduate student Mark Psiaki completed a study of optimal trajectories for penetration of microbursts when encounter is unavoidable. His initial work (reported earlier) showed that simple control laws could greatly reduce an aircraft's response to wind shear. His 1987 Ph.D. thesis

presents flight envelopes within which optimal application of throttle and pitch control produce acceptable deviations from nominal takeoff and landing flight paths for a jet transport and a propeller-driven general aviation aircraft. Although the response mechanism is the same, jet transport and general aviation aircraft behave somewhat differently in microbursts; the larger, heavier aircraft are more adversely affected by variations in the horizontal wind, while the smaller, lighter aircraft have greater difficulty with the downdraft. These findings are summarized in Ref. 1.

The emphasis of current wind shear research, being pursued by graduate student Alex Stratton under a separate NASA grant, is on developing an expert system for wind shear avoidance [2,3]. Our principal objectives are to develop methods for assessing the likelihood of wind shear encounter (based on real-time information in the cockpit), for deciding what flight path to pursue (e.g., abort, go-around, normal climbout, or glide slope), and for using the aircraft's full potential to combat wind shear. This study requires the definition of deterministic and statistical techniques for fusing internal and external information, for making "go/no-go" decisions, and for generating commands to the aircraft's autopilot and flight directors in automatic and manually controlled flight.

Undetected system failures and/or inadequately defined recovery procedures have contributed to numerous air carrier incidents and accidents. The infamous DC-10 accident at Chicago's O'Hare Airport, in which loss of an engine pod, subsequent loss of subsystems, and asymmetric wing stall led to disaster, provides a prototype for the kind of tragedy that could be averted by intelligent flight control systems. (An intelligent control system is one that uses artificial intelligence concepts, e.g., an expert systems program, to improve performance and failure tolerance.) Although many methods of modern control theory are applicable, the scope of the problem is such that none of the existing theories provides a complete and practical solution to the problem. At the same time, heuristic logic may be applicable, but it has yet to be stated in satisfactory format.

Graduate student David Handelman has developed a knowledge-based reconfigurable flight control system that is implemented with the Pascal programming language using parallel microprocessors. This expert system could be considered a prototype for a failure-tolerant control system that can be constructed using existing hardware. The knowledge-based flight control system is specified initially and tested using the LISP programming language. When desired logic is determined, the corresponding Pascal code is generated automatically. Concepts for rule-based learning and

control that can be used in such systems are contained in two technical papers and in Mr. Handelman's Ph.D. thesis [4 - 6].

Helping a pilot make quick decisions under high workload conditions is important for aircraft missions of all types. In research principally supported by an Army/Navy grant but reported at numerous quarterly reviews of the Joint University Program, Brenda Belkin has developed an expert system of expert systems called AUTOCREW. In her M.S.E. thesis [7], Ms. Belkin uses the paradigm of a hypothetical aircraft crew to facilitate the assignment of tasks, rules, and data within parallel knowledge bases. AUTOCREW performs a cyclical search in which the Director expert system, the electronic analog of the aircraft commander, establishes goals that invoke the crew-member expert systems. The crew members then perform such tasks as observation, monitoring, and control in response to continuing needs as well as special requests from the Director. The application of AUTOCREW to civil jet transports is apparent, and Ms. Belkin has participated in the Joint University Program with this in mind.

Development of a real-time cockpit simulator continued during the year. The simulator provides a single-person crew station with both conventional and advanced control devices; it currently is programmed to simulate the Navion single-engine general aviation airplane. Displays for the "out-the-window" view and the control panel devices are generated entirely by computers and are presented on color cathode-ray tubes. The external view is generated and displayed by a Silicon Graphics IRIS 3020 Workstation, which has 1024 x 768-pixel resolution and can perform over 85,000 3-D transformations per second. A central computing unit performs dynamic and control calculations, accepts analog inputs, drives the panel displays, and commands the external view. It is a special-purpose Multibus computer employing parallel 80286 processors and special-purpose graphics boards, which are controlled by an IBM PC-AT computer. Senior Jeffrey Seinwill developed an all-attitude artificial horizon display for the simulator during the year [8].

For all practical purposes, the production of small general aviation (GA) airplanes in the U.S. has come to an end. Fewer than a thousand four-seaters were produced in 1987, and most of the principal American GA manufacturers have all but abandoned the business. Although there are many reasons for the erosion of this industry, outmoded technology is a major factor. General aviation has a potentially significant role to play not only in the National Transportation System but in the economic infrastructure of the country. Revival demands reinvention of the small plane, in

what might be called a Modern-Equipment General Aviation airplane. There is a wealth of fundamental research to be done in this area, much of it already under way in the Air Transportation Technology Program. Senior Joakim Karlsson's independent work project dealt with the design of such an aircraft [9] using modern aerodynamic, structural, and control technology. Senior Bruce Weiner conducted an economic review of the price-performance characteristics of small aircraft during the period from 1970 to 1987 that graphically illustrates the effects of increased product liability costs [10].

Air commerce is a significant factor in the nation's economy, involving hundreds of millions of passenger trips and tens of billions of dollars in operating revenue each year. Recent revenue growth rates average 10 percent per year; much of this growth can be traced to the deregulation of the nation's airlines in 1978. This growth has caused severe air traffic control problems, most often demonstrated in flight delays and reflected by growing concerns for passenger safety. Despite the aggregate economic benefits of deregulation, many people are questioning whether the benefits outweigh the perceived costs of reduced confidence and increased delays. Senior Lawrence Neubauer analyzes alternatives for the air traffic control system in his thesis, giving particular attention to the institutional structure of the FAA [11].

Control system robustness is defined as the ability to maintain satisfactory stability or performance characteristics in the presence of all conceivable system parameter variations. While assured robustness may be viewed as an alternative to gain adaptation or scheduling to accommodate known parameter variations, more often it is seen as protection against uncertainties in plant specification. Consequently, a statistical description of control system robustness is consistent with what may be known about the structure and parameters of the plant's dynamic model. Guaranteeing robustness has long been a design objective of control system analysis, although in most instances, insensitivity to parameter variations has been treated as a deterministic problem. Graduate student Laura Ryan is investigating a simple numerical procedure for estimating the *stochastic robustness* of control systems [12-14]. Monte Carlo evaluation of the system's eigenvalues allows the *probability of instability* and the related *stochastic root locus* to be estimated. This analysis approach treats not only Gaussian parameter uncertainties but non-Gaussian cases, including uncertain-but-bounded variations. Trivial extensions of the procedure admit alternate discriminants to be considered. Thus, the probabilities that stipulated degrees of instability will be exceeded or that closed-loop roots will leave

desirable regions also can be estimated. Results are particularly amenable to graphical presentation.

There is growing interest in the use of neural networks for computational decision-making and control, brought about by the advent of small, fast, inexpensive computers. The neural network paradigm offers a potentially attractive structure for flight control systems that adapt to changing flight conditions and system failures, but much is to be learned about the practicality of such an approach. Graduate student Dennis Linse has begun to examine this potential. To date, he has formulated various multi-layer networks to trim the longitudinal motions of a twin-jet transport. The network is resilient in the face of elemental failures and provides moderately accurate open-loop control of throttle and elevator over a wide range of flight conditions.

ANNOTATED REFERENCES OF 1988-89 PUBLICATIONS

1. Psiaki, M., and Stengel, R.F., "Performance Limits for Optimal Microburst Encounter," *Proceedings of the AIAA 15th Atmospheric Flight Mechanics Conference*, Minneapolis, Aug 1988, pp. 358-370.

The performance limits of optimal aircraft control strategies for microburst encounter are presented. The purpose is to determine the "edges of the envelope" for no-accident aircraft penetration of microburst wind shear. Over 1,100 optimal trajectories have been computed for jet transport and general aviation aircraft flying through idealized microbursts. They have been generated using a Successive Quadratic Programs trajectory optimization algorithm, which directly handles inequality constraints. Qualitative aspects of the best strategies provide a composite picture of good control in a microburst. Variations of the no-accident performance with microburst type, intensity, length scale, and location define performance limits.

Optimal performance limits show three length-scale regimes. At short length scales, hazards usually associated with gustiness predominate. At intermediate length scales, a degraded ability to maintain flight path and/or vertical velocity sets the limiting microburst intensities for no-accident performance. At very long microburst length scales, the hazards associated with intense steady winds are the critical safety limits. The abil-

ity to successfully transit a microburst also varies strongly with microburst location. The performance limits show that both aircraft types, if controlled properly, can penetrate very severe microbursts. Nevertheless, even the best control strategies have their limits. The jet transport performance limits occur at higher microburst intensities than the general aviation limits.

2. Stengel, R.F., and Stratton, D.A., "An Expert System for Wind Shear Avoidance," presented at the Second Combined Manufacturers and Technology Airborne Wind Shear Review Meeting, Williamsburg, VA, Oct 1988.

Flight in strong wind shears, especially microbursts, poses a unique and severe hazard to aircraft. The disturbance caused by the wind field may literally exceed the performance characteristics of the aircraft, making safe transit impossible even with optimal guidance and control strategies. An unusual degree of piloting skill may be required to successfully elude danger. Nevertheless, planes fly in moderate wind shear all the time; pilots learn to handle crosswinds, gustiness, and moderate frontal activity. The problem is that microbursts are random, rare phenomena; pilots do not develop the needed skills for coping with wind shear through normal experience. The typical pilot is likely to be confronted with a life-threatening wind shear only once or twice during an entire flying career; hence, it is unlikely that he or she can learn all the important signs of wind shear and maintain a high level of proficiency in the proper control procedures.

On-board computation provides an excellent opportunity to assist the pilot in surviving encounters with severe wind shears, but the logic that must be executed in real time is complex and must have sufficient inputs for framing decisions about appropriate control actions. The computer program(s) and hardware to perform this task must have attributes of expert systems and control systems, they must account for the limitations of aircraft performance, and they must operate in real time. At least as important as its technical specifications, the on-board system must provide a satisfactory interface with the flight crew, which bears the ultimate responsibility for assuring safety. This means not only that the system must deduce near-optimal strategies and tactics for emergency situations but that it must distinguish between truly hazardous conditions and the more likely alternatives associated with normal aircraft operations.

A program to investigate ways of protecting against wind shear has begun at Princeton University, with current emphasis on developing an

expert system for wind shear avoidance. Our principal objectives are to develop methods for assessing the likelihood of wind shear encounter (based on real-time information in the cockpit), for deciding what flight path to pursue (e.g., abort, go-around, normal climbout, or glide slope), and for using the aircraft's full potential to combat wind shear. This study requires the definition of deterministic and statistical techniques for fusing internal and external information, for making "go/no-go" decisions, and for generating commands to the aircraft's autopilot and flight directors in automatic and manually controlled flight.

The expert system for pilot aiding is based on results of the Integrated FAA Wind Shear Program. Its two-volume manual presents an overview, pilot guide, training program, and substantiating data and provides guidelines for this initial development. The WindShear Safety Advisor currently being developed at Princeton contains over 140 rules and is coded in the LISP programming language for implementation on a Symbolics 3670 LISP Machine.

3. Stengel, R.F., and Stratton, D.A., "An Expert System for Wind Shear Avoidance," presented at the 1989 American Control Conference, Pittsburgh, June 1989.

A study of intelligent guidance and control concepts for protecting against the adverse effects of wind shear during aircraft takeoffs and landings is being conducted, with current emphasis on developing an expert system for wind shear avoidance. Principal objectives are to develop methods for assessing the likelihood of wind shear encounter (based on real-time information in the cockpit), for deciding what flight path to pursue (e.g., takeoff abort, landing go-around, or normal climbout or glide slope), and for using the aircraft's full potential for combating wind shear. This study requires the definition of both deterministic and statistical techniques for fusing internal and external information, for making "go/no-go" decisions, and for generating commands to the aircraft's autopilot and flight directors for both automatic and manually controlled flight. The program has begun with the development of the WindShear Safety Advisor, an expert system for pilot aiding that is based on the FAA Windshear Training Aid, a two-volume manual that presents an overview, pilot guide, training program, and substantiating data provides guidelines for this initial development. The WindShear Safety Advisor expert system currently contains over 200 rules and is coded in the LISP programming language.

4. Handelman, D.A., and Stengel, R. F., "Rule-Based Mechanisms of Learning for Intelligent Adaptive Flight Control," *Proceedings of the 1988 American Control Conference*, Atlanta, June 1988, pp. 208-213.

This paper investigates how certain aspects of human learning can be used to characterize learning in intelligent adaptive control systems. Reflexive and declarative memory and learning are described. It is shown that model-based systems-theoretic adaptive control methods exhibit attributes of reflexive learning, whereas the problem-solving capabilities of knowledge-based systems of artificial intelligence are naturally suited for implementing declarative learning. Issues related to learning in knowledge-based control systems are addressed, with particular attention given to rule-based systems. A mechanism for real-time rule-based knowledge acquisition is suggested, and utilization of this mechanism within the context of failure analysis for fault-tolerant flight control is demonstrated.

5. Handelman, D.A., and Stengel, R. F., "Perspectives on the Use of Rule-Based Control," *Proceedings of the IFAC Workshop on Artificial Intelligence in Real-Time Control*, Swansea, UK, Sept 1988.

This paper addresses issues regarding the application of artificial intelligence techniques to real-time control. Advantages associated with knowledge-based programming are discussed. A proposed rule-based control technique is summarized and applied to the problem of automated emergency procedure execution. Although emergency procedures are by definition predominantly procedural, their numerous evaluation and decision points make a declarative representation of the knowledge they encode highly attractive, resulting in an organized and easily maintained software hierarchy. Simulation results demonstrate that real-time performance can be obtained using a microprocessor-based controller. It is concluded that a rule-based control system design approach may prove more useful than conventional methods under certain circumstances, and that declarative rules with embedded procedural code provide a sound basis for the construction of complex control systems.

6. Handelman, D.A., "A Rule-Based Paradigm for Intelligent Adaptive Flight Control," Ph. D. Thesis, Princeton University, Report No. 1858-T, April 1989.

Although fault tolerance always has been an important aspect of aircraft design, the reduced static stability and increased maneuverability of modern aircraft complicate the problem by shortening the amount of time available to detect, identify, and adjust for component failures. This dissertation investigates the use of highly integrated symbolic and numeric processing in real-time knowledge-based systems for enhanced automatic aircraft failure accommodation. A rule-based control technique is proposed whereby procedural activity is attained through the manipulation of declarative expressions. Rules are used to encode common-sense dependencies, to incorporate expert knowledge on specific situations, and to invoke algorithmic mathematical procedures. Task execution occurs as a by-product of search through these knowledge-base rules. Also proposed is a rule-based controller development system that utilizes a high-level symbolic LISP environment for preliminary system design. Automatic LISP-to-Pascal knowledge-base translation is used to provide dramatically increased execution speed and an environment for highly integrated symbolic and numeric computation. The utility of the control technique is demonstrated through the construction of a multi-processor Rule-Based Flight Control System (RBFCS) for a CH-47 tandem-rotor helicopter. The RBFCS is shown to accommodate multiple simulated failures affecting the electrical, hydraulic, and stability augmentation subsystems of the helicopter. It is concluded that declarative rules with embedded procedural code provide a sound basis for the construction of complex control systems.

7. Belkin, B.L., "Cooperative Rule-Based Systems for Aircraft Navigation and Control," M.S.E. Thesis, Princeton University, Report No. MAE-1856-T, June 1989.

This thesis proposes a design methodology for the development of multiple cooperating rule-based systems for aircraft. Nine systems, collectively called AUTOCREW were designed to automate functions and decisions. The organization of tasks is described, details of knowledge-base development and implementation are given, and performance metrics for evaluating the workload of each knowledge base are demonstrated. Several test scenarios were evaluated using an interactive graphical simulation on an IBM PC-AT computer. Software tools developed to aid in high-level design also are described. Results show that these tools facilitate rapid

prototyping of a complex system exhibiting knowledge-base cooperation, satisfactory logic flow, and human pilot-AUTOCREW interaction.

Design of one of the component expert systems, the Navigation Sensor Management (NSM) module, was pursued in considerable detail. This problem was chosen because it presented the challenge of designing an expert system from simulation data; that is, from quantitative test results. The NSM Expert was systematically derived from Kalman filter covariance data for simulated missions flown with seven different navigation system types. This development used Analysis of Variance (ANOVA) and the "ID3" algorithm. The function of the NSM Expert was to determine optimal navigation strategies from a set of available sensors based on a root-sum-square metric. Results show that the NSM Expert predicted position accuracy between 65 and 100 percent of the time for a specified "navaid" configuration and aircraft trajectory; hence, this decision-making logic could be incorporated in a scheme for best navaid selection. The systematic nature of the ANOVA/ID3 method makes it broadly applicable to expert system design when experimental or simulation data are available.

8. Seinwill, J., "Design and Testing of Cockpit Displays for a Flight Simulator," Princeton University Senior Independent Work Project Report, May 1988.

A program to simulate an artificial horizon display on a CRT was developed and tested. The code exhibits real-time performance using a Matrox Multibus graphics board to generate an image of the aircraft's pitch and roll attitudes in maneuvering flight. The display can be masked to yield circular or rectangular format, and additional alphanumeric or graphical information can be presented within the mask. A pitch "ladder" can be superimposed on the artificial horizon to show quantitative data.

9. Karlsson, J., "Preliminary Design for a Modern Equipment General Aviation (M.E.G.A.) Aircraft," Princeton University Senior Independent Work Project Report, May 1988.

A single-engine/propeller aircraft design is proposed to revitalize the U.S. general aviation industry. The objective of the design is to improve safety over existing designs, improve cost efficiency, and to provide easy-to-fly aircraft, while maintaining good performance qualities. The design approach is defined, followed by the resulting design procedure, and a preliminary design is presented. These objectives are realized through the

use of modern, but proven, technology, as well as a high degree of system redundancy.

The Modern Equipment General Aviation (M.E.G.A.) airplane is designed to carry a payload of one pilot and three passengers, as well as two children on a folding seat or 100 kg of baggage. The range specification is 1000 km, the cruising speed is 90 m/s, and the landing speed is 25 m/s. The resulting design incorporates a stratified-charge rotary engine and three lifting surfaces: a laminar-flow wing, a T-tail, and a small flapped canard in the propeller slipstream. All lifting surfaces have mechanically uncoupled controls. The wing has 50%-span simple flaps, and the wing tips are sheared to improve aerodynamic efficiency. Large cockpit windows afford good visibility, and limited use is made of composite materials to reduce weight and insure partial laminar flow over the wing.

The first phases of the preliminary design were based on conventional analytical procedures. Two computer programs, *LinAir* and *Paper Airplane*, were used to optimize design details such as wing twist and static stability to produce the final design.

10. Weiner, B.W., "Public Policy and Its Impact on The Decline Of General Aviation: Directions For Future Improvement," Senior Thesis, Woodrow Wilson School of Public and International Affairs, Princeton University, May 1988.

General aviation has not participated in the recent upswings in the economy. This year represented the ninth consecutive year of the decline in shipments of U.S.-built general aviation airplanes. The number of private pilots has been following a downtrend as well. The cause of the decline and future directions for general aviation are the topics of this thesis.

The purpose of the inquiry is to examine some of the external influences driving general aviation pilots and aircraft out of American skies. It begins by examining the benefits of general aviation in both quantitative and qualitative terms. It considers the effect that the FAA has had and the policy changes that would benefit general aviation. It develops a "hedonic" pricing model to examine the economic demand for general aviation aircraft, focusing on single-reciprocating-engine configurations. The thesis concludes with policy recommendations.

The pricing model is a function of cruise speed, range, useful load, rate of climb, landing gear (retractable or not), and aircraft age. An eight-term polynomial was found to fit the logarithm of current average price with an R^2 statistic of 0.93 for a 17-year period beginning in 1970. The resulting index was applied to the general aviation fleet on an averaged, annualized basis to determine the relative quality of available aircraft. This measure suggests that both quality and aircraft price increased during the period, although there was a downturn in both during the final two years. The price index tracked the gross national product rather well until the same point in time. The author presents evidence that this relative reversal is due to skyrocketing product liability costs, which impact established manufacturers with many aircraft in the field most heavily. Liability costs have smaller impact on foreign competitors, who do not have as large an American fleet and thus have fewer claims. Tort reform is seen as a principal means of solving this problem.

11. Neubauer, L. A., "The Air Traffic Control System: Problems and Prospects," Senior Thesis, Woodrow Wilson School of Public and International Affairs, Princeton University, April 1988.

Air commerce is a significant factor in the nation's economy, involving hundreds of millions of passenger trips and tens of billions of dollars in operating revenue each year. Recent revenue growth rates average 10 percent per year; much of this growth can be traced to the deregulation of the nation's airlines in 1978. This growth has caused severe air traffic control problems, most often demonstrated in flight delays and reflected by growing concerns for passenger safety. Despite the aggregate economic benefits of deregulation, many people are questioning whether the benefits outweigh the perceived costs of reduced safety and increased delays. Elected officials have responded by holding numerous hearings and introducing bills providing for a range of alternatives from total re-regulation to dismantling the Federal Aviation Administration.

The FAA faces a growing crisis of confidence in its ability to provide air traffic control. In response to funding, procurement, staffing, and oversight problems, three alternative solutions were analyzed in this thesis: reestablishing the FAA as an independent agency, setting up a government-owned corporation to run air traffic control, and privatizing air traffic control. After extensive review, it was concluded that the first alternative provides the best opportunity for resolving this dilemma, while creating the fewest new problems. An independent FAA would provide the opportunity for a revitalization of the Agency by reducing funding concerns,

cutting outside influence over the organization, and providing the Administrator with more flexibility to appoint staff and to recognize meritorious service. Resolution of the concerns facing air traffic control depends upon the joint efforts of FAA, DOT, Congress, and the Administration, as well as the users of the system.

12. Stengel, R.F., and Ryan, L.E., "Stochastic Robustness of Linear Control Systems," presented at the 1989 Conference on Information Sciences and Systems, The Johns Hopkins University, Baltimore, Mar 1989.

A simple numerical procedure for estimating the *stochastic robustness* of a linear, time-invariant system is described. Monte Carlo evaluation of the system's eigenvalues allows the *probability of instability* and the related *stochastic root locus* to be estimated. This definition of robustness is an alternative to existing deterministic definitions that address both structured and unstructured parameter variations directly. This analysis approach treats not only Gaussian parameter uncertainties but non-Gaussian cases, including uncertain-but-bounded variations. Trivial extensions of the procedure admit alternate discriminants to be considered. Thus, the probabilities that stipulated degrees of instability will be exceeded or that closed-loop roots will leave desirable regions also can be estimated. Results are particularly amenable to graphical presentation.

13. Stengel, R.F., and Ryan, L.E., "Stochastic Robustness," presented at the SIAM Conference on Control in the 90's," San Francisco, May 1989.

This paper is an oral-only extension of the above paper with extended numerical results for the Doyle LQG counterexample. In particular, the comparison of stochastic robustness with singular-value analysis is pursued; whereas the latter provides only qualitative guidelines for "loop transfer recovery," the former provides a specific solution for the amount of robustness recovery required as a function of parameter uncertainty.

14. Stengel, R.F., and Ryan, L.E., "Multivariate Histograms for Analysis of Linear Control System Robustness," presented at the 1989 American Control Conference, Pittsburgh, June 1989.

A simple numerical procedure for estimating the *stochastic robustness* of a linear, time-invariant system is described. Based on Monte Carlo evaluation of the system's eigenvalues, this analysis approach introduces the

probability of instability as a scalar measure of stability robustness. The related *stochastic root locus*, a portrayal of the root probability density, provides insight into robustness characteristics. Parameter variations are not limited to Gaussian parameter uncertainties; non-Gaussian cases, including uncertain-but-bounded variations, can be considered as well. Confidence intervals for the scalar probability of instability address computational issues inherent in Monte Carlo simulation. An example demonstrates stochastic robustness as applied to an aircraft control system in which parameters are alternately considered to have Gaussian, uniform, or binary probability distributions.